22.033 Process Heat

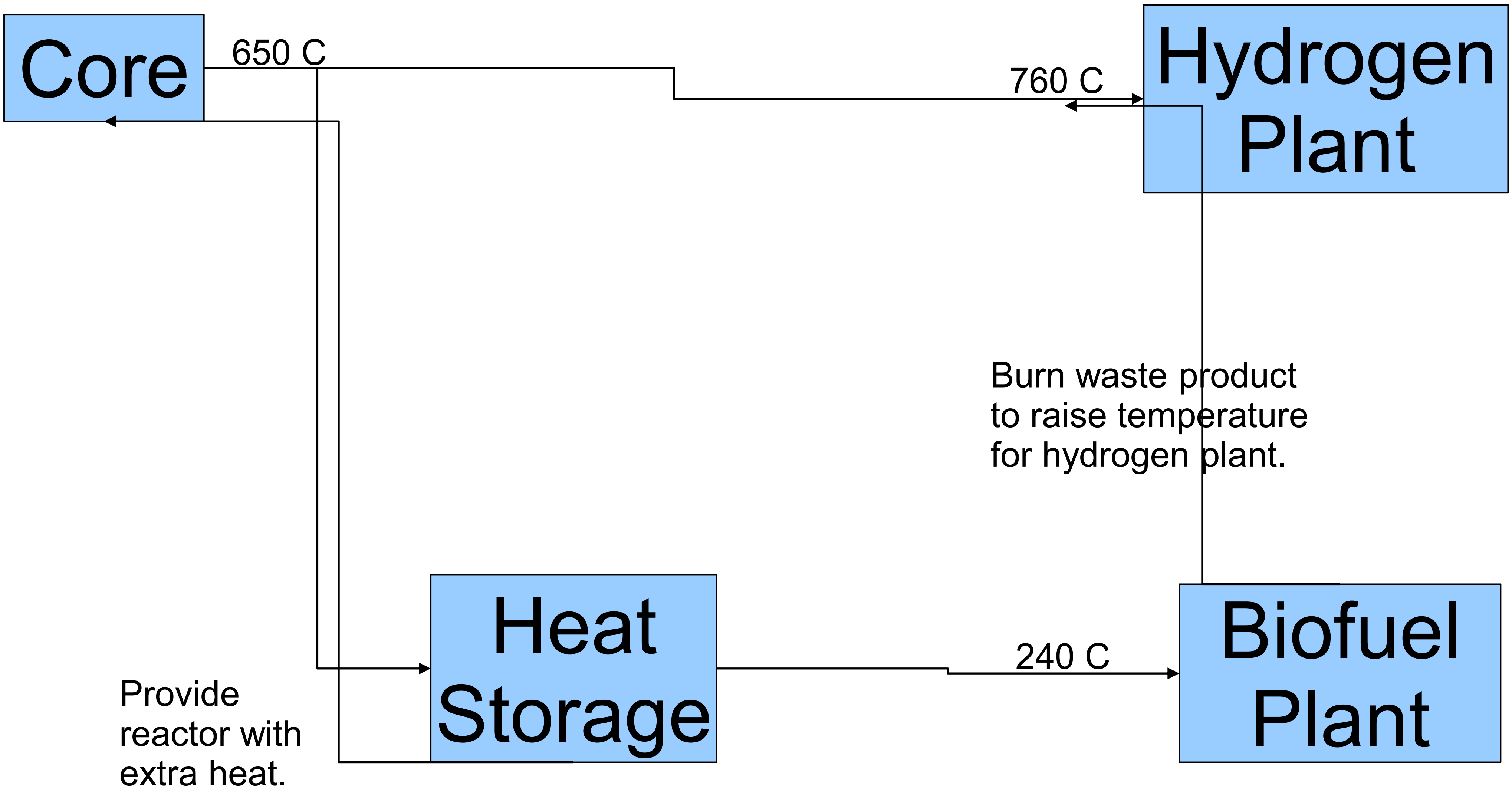
Lauren Ayers
Sarah Laderman
Aditi Verma
Anonymous student

Presentation 1
October 5, 2011

Outline

- System Layout
- Heat Exchanger Designs
- Heat Storage Options
- Heat Transport
- Future Work

System Layout



Types of Heat Exchangers Investigated

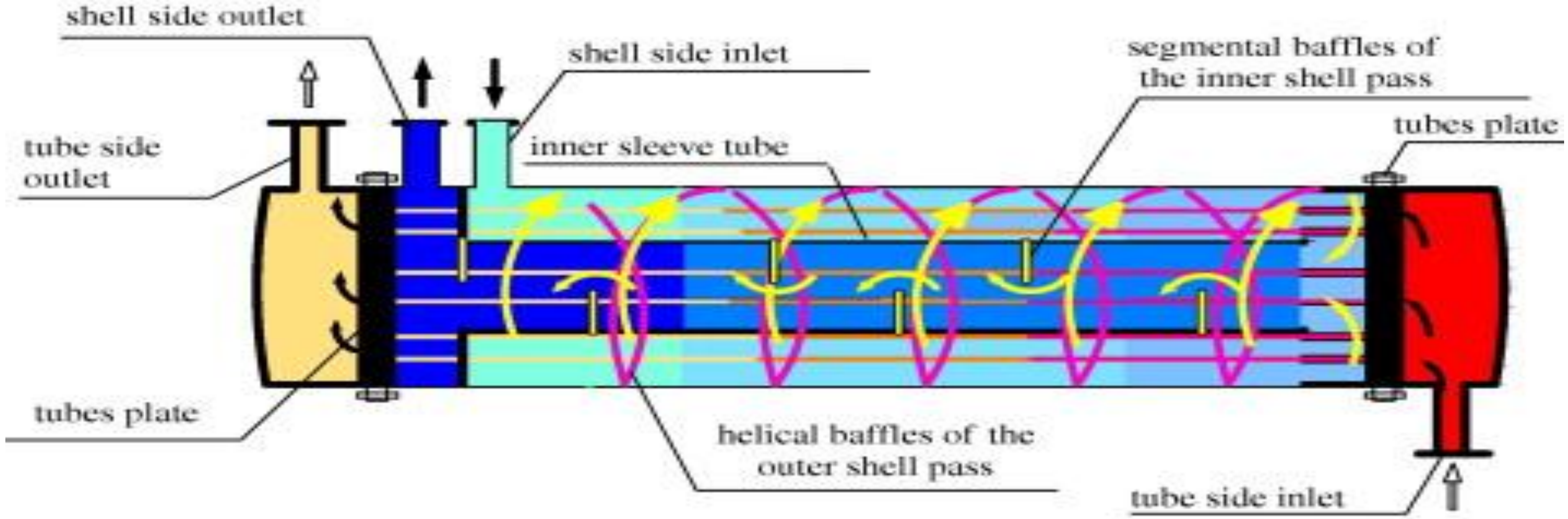
- Standard shell and tube
- Printed circuit heat exchangers
- Helical shell and tube
- Thermosyphons

Criteria for Selecting a Heat Exchanger

- Operating temperature and pressure
- High heat transfer performance
- Effectiveness
- Fouling

Courtesy of MERUS GmbH. Used with permission.

Multiple Pass Shell and Tube with Continuous Helical Baffles



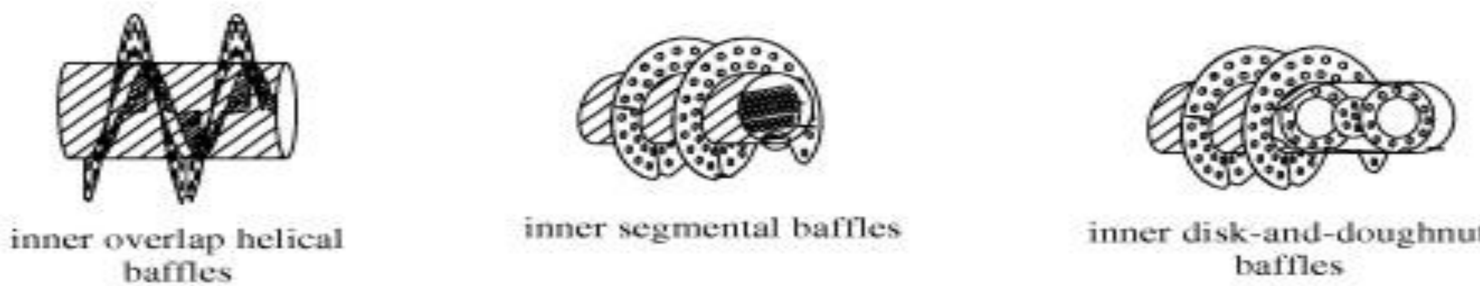


Photo from Q. Wang

Max. operating pressure: ~70 MPa

Max. operating temperature: dependent on materials

Induced turbulence + high shear stress = less fouling

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Printed Circuit Heat Exchangers (PCHEs)

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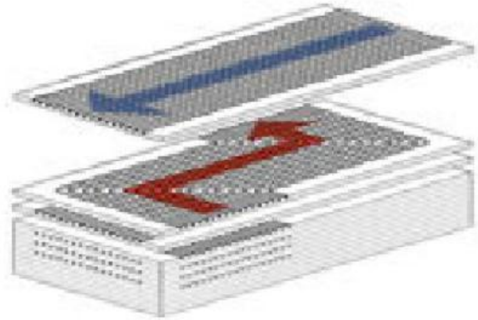
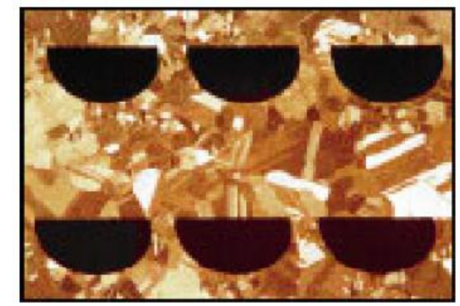
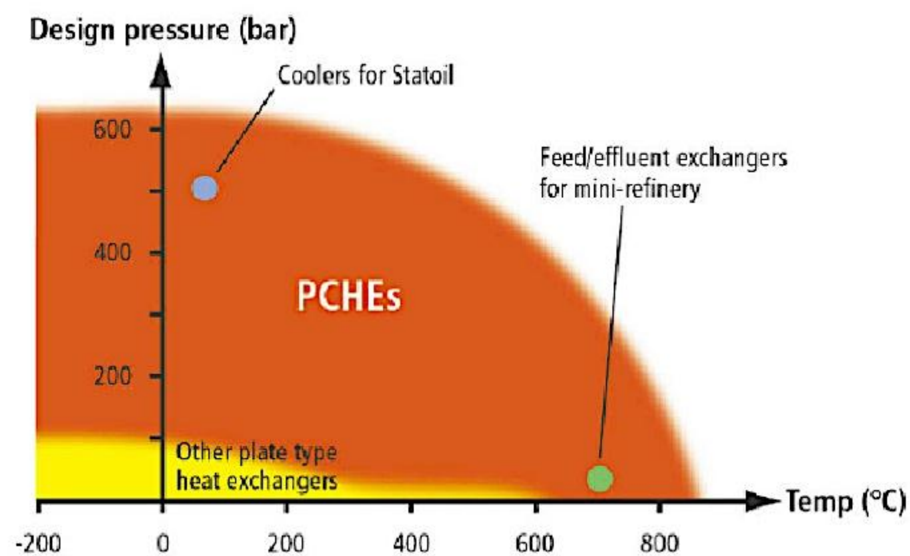
- All-metal HXs made of diffusion bonded plates
- Long design life (up to 60 years)
- Compact, mass/duty ratio of 0.2 tons/MW
- High operating temperatures (up to 900 C) and pressure (60 MPa)
- High surface area density (2500 m2/m3)
- Hybrid fin and plate type PCHE, H2X, suitable for coupling gaseous and liquid working fluids



Diffusion bonding of PCHE plates (Heatric™)



Cross sectional view of the semi-circular passages (Heatric™)



Current operating experience of Heatric™ PCHEs
(Gezelius, K., "Design of Compact Intermediate Heat Exchangers for Gas Cooled Fast Reactors," Bachelors' & Masters' Thesis, MIT, June 2004.)

Heat Exchanger Requirements

- Operating Temperatures
  - HX connected to CO2 loop: 650-900 ºC
  - Hydrogen plant: 700-900 ºC
  - Biofuels plant: 240-300 ºC
  - Heat storage: 300-500 ºC
- Standardized heat exchanger design will reduce plant complexity and operating and maintenance costs

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Heat Exchanger Configurations

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- Two HX instead of single high temperature HX to increase design life
- Connect process heat system in parallel or series
- Remove heat from the secondary cycle before the power conversion system
  - Need to decide with core
- HX decisions will depend on flow rates and temperatures provided by core and needed by biofuels and hydrogen plants

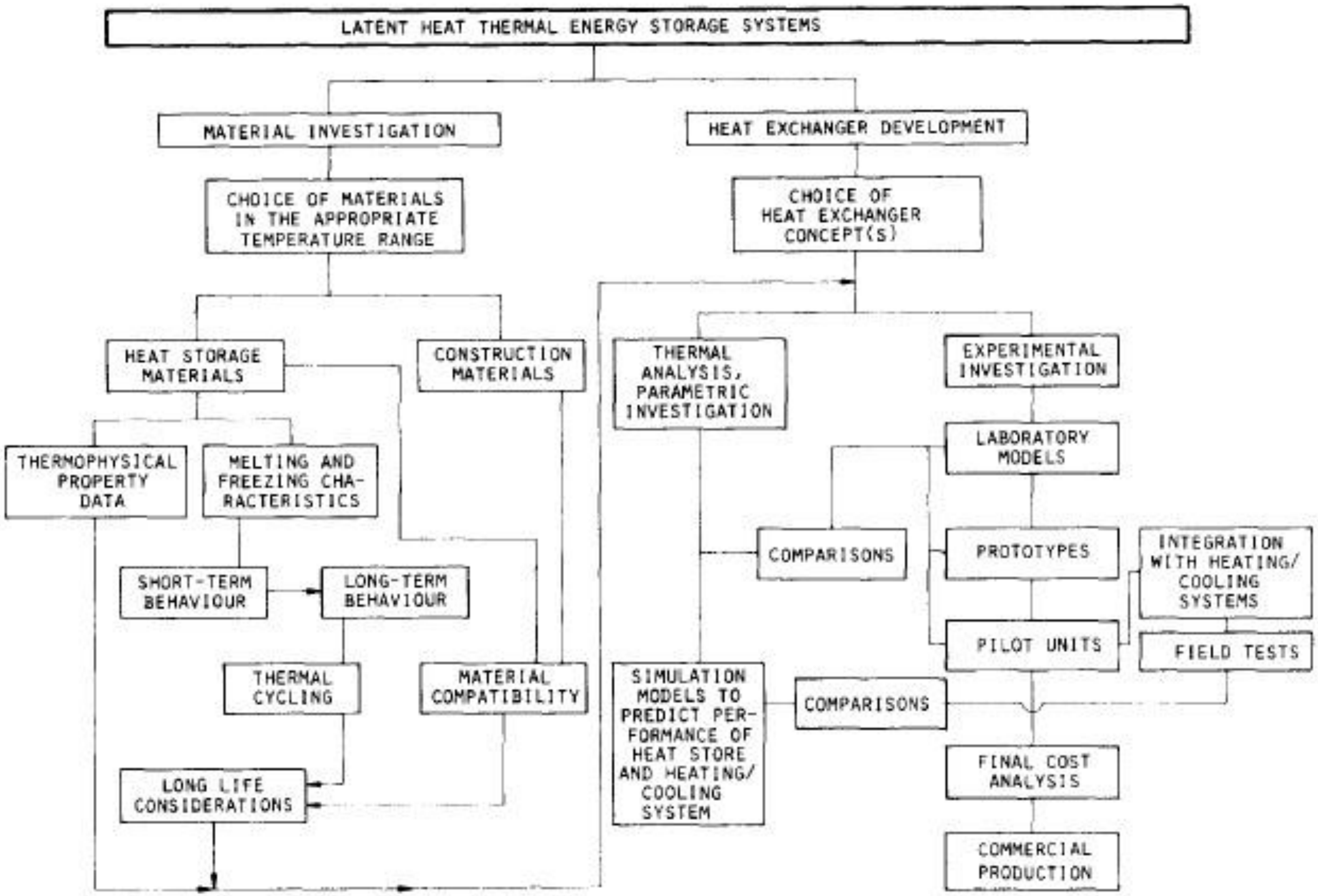
Benefits of Heat Storage

- Plateau energy fluctuations during daily cycles
- Providing lower temperature to biofuels without wasting heat

Heat Storage Options

- Latent Heat vs. Sensible Heat
  - Latent – storing energy in chemical bonds
  - Sensible – using change of temperature of material to store heat (specific heat capacity)
- Decided on latent heat
  - Can store higher energy density
  - Provides heat at constant operating temperature
  - Uses phase change materials

Phase Change Material Decision Tree



PCM Selection

- Must have melting point in desired operating temperature range
- Ideal Characteristics:
  - High latent heat of fusion per unit mass
  - High density
  - High specific heat
  - High thermal conductivity
  - Chemically stable
  - Non-corrosive to the containment material

Liquid-Solid PCMs

- Paraffins & Salt Hydrates
  - Operating temperature too low
- Salts
  - Large range of operating temperatures
  - Issues: corrosion & low thermal conductivity
- Metals
  - Desirable thermodynamic properties
  - Issues: freezing can cause stresses to containment, temperature range is limited

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Salt and Metal PCMs

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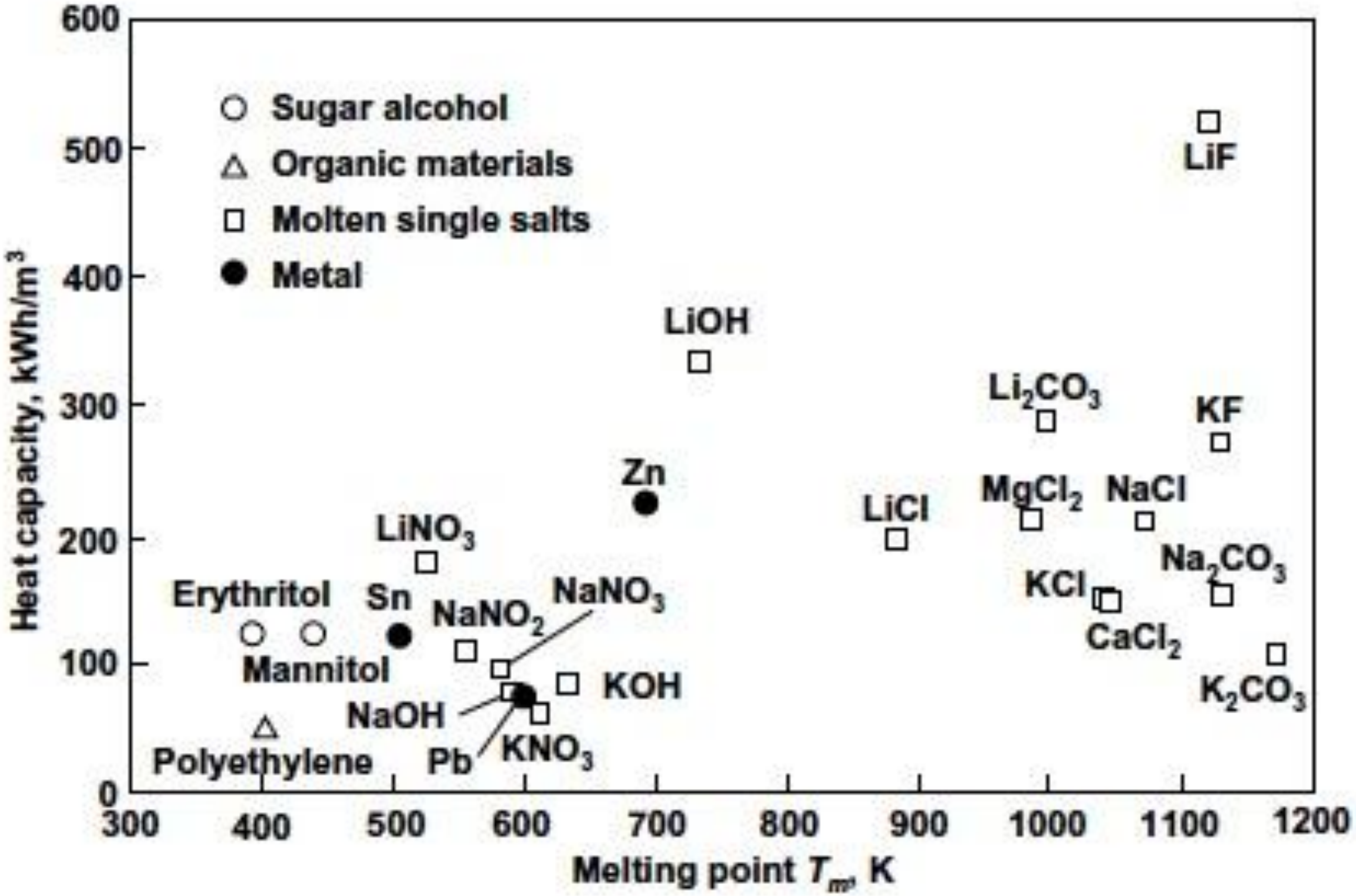

Looking Ahead

- Containment structure cannot be designed until a PCM is chosen
  - Material compatibility concerns
- Volume of material is dependent on:
  - Thermodynamic properties of the material
  - Amount of energy that needs to be stored

Heat Transport Methods

- Thermosyphons
  - Uses gravity and phase changes to move heat long distances with minimal heat loss
  - Highly dependent on location of plant
- Heat pipes
  - Can use capillary action and if in correct orientation, gravity can assist
  - Can also use centripetal, electrokinetic, magnetic, and osmotic forces
    - Not as practical for long distances and not as well developed technologies

Heat Transport Decisions

- Method of condensate transport determined by distance between plants
  - Will model hydrogen plant explosions and biofuel plant fires to determine safe distances
- Material and working fluid determined by HX choice and temperature environment

Future Work

- Finalize heat exchanger and heat storage designs
- Model system once initial outputs/inputs are available
  - Matlab, EES, RELAP
- Heat sink as a safety measure at hydrogen plant
- Determine plant distances as more data becomes available

Questions?